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Gad Ben-Oliel [a]; Surya Kant [a]; Michael Naim [a]; Haim D. Rabinowitch [a]; Gary R. Takeoka [b]; Ron G. Buttery [b]; Uzi Kafkafi [a]
[a] Institutes of Plant Sciences and Genetics in Agriculture and of Biochemistry, Food Science and Nutrition, The Hebrew University of Jerusalem, Rehovot, Israel [b] Western Regional Research Center, US Department of Agriculture, Agricultural Research Service, Albany, California, USA

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Effects of Ammonium to Nitrate Ratio and Salinity on Yield and Fruit Quality of Large and Small Tomato Fruit Hybrids

Gad Ben-Oliel,[1] Surya Kant,[1] Michael Naim,[1] Haim D. Rabinowitch,[1] Gary R. Takeoka,[2] Ron G. Buttery,[2] and Uzi Kafkafi[1,*]

[1]Institutes of Plant Sciences and Genetics in Agriculture and of Biochemistry, Food Science and Nutrition, The Hebrew University of Jerusalem, Rehovot, Israel
[2]Western Regional Research Center, Agricultural Research Service, US Department of Agriculture, Albany, California, USA

ABSTRACT

Tomato cultivars respond differently to nitrogen (N) sources and to saline conditions, in terms of both yield and fruit quality. Interactions between salinity and NH_4^+/NO_3^- ratios with tomato

*Correspondence: Uzi Kafkafi, Institutes of Plant Sciences and Genetics in Agriculture and of Biochemistry, Food Science and Nutrition, The Hebrew University of Jerusalem, Rehovot, Israel; E-mail: kafkafi@agri.huji.ac.il.

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genotypes were studied. The effect of four ammonium levels (0, 1, 2, 4 mM of total 8 mM N) and two salinity levels (0 and 45 mM NaCl) on cv. "R-144", and the effect of two salinity levels (0 and 45 mM NaCl) on four tomato hybrids ("R-144", "R-175", "FA612", and "FA624") were studied in two greenhouse experiments. The effects of two NH_4^+ levels, (0 and 2 mM out of total N at 8 mM), and two salinity levels (0 and 20 mM NaCl) on large-fruit ("R-144") and small-fruit ("FA612") tomato hybrids were also studied in a net-house. The NaCl at 45 mM resulted in a smaller leaf area index (LAI), lower plant dry matter and lower fruit yield than controls. Addition of 1 mM NH_4^+ to the nutrient solution contributed to improved growth. Genotypes bearing large fruits were more prone to suffer yield losses under saline conditions than those with small fruits. In the second experiment, salinity treatment resulted in improved fruit TSS, EC and titratable acidity in all of the hybrids except of "FA612". Fruit TSS was inversely correlated with yield. However, the ratio in TSS decline versus yield varied among the hybrids. At mild salinity (20 mM NaCl), fruit TSS and titratable acidity were significantly increased in "R-144" while yield was slightly decreased. Transpiration rate decreased with the presence of ammonium in the nutrient solution in both hybrids. The highest and lowest values were obtained for "FA612" and "R-144", respectively. The detrimental effect of salinity is mainly attributed to the decrease in LAI and the subsequent reduction in water uptake, resulting in low fruit weight. Addition of 1 mM ammonium to 7 mM nitrate in the nutrient solution had an ameliorating effect on tomato fruit yield under salinity.

Key Words: Total soluble solids; pH; Electrical conductivity; Titratable acidity; Blossom end rot; Water uptake.

INTRODUCTION

Tomato is one of the most important greenhouse vegetables in semi-arid regions, where soil and groundwater salinity are pre-dominant. Salinity is known to improve tomato fruit quality,[1] but yields are usually low due to lower water intake by the fruit. Salinity also increases the incidence of blossom-end rot (BER).[2,3]

Under intensive fertigation, nitrogen not only affects plant growth, it may also alter the salinity tolerance of plants depending on its ionic form. The beneficial effects of nitrate under saline conditions have been attributed to the antagonism between NO_3^- and Cl^- ions,[4] whereas growth suppression by ammonium probably results from a shortage of sugar in the roots,[5] or from inhibition of nitrate reductase activity in roots and shoots.[6] Some reports, however, indicate that combined NH_4^+ and NO_3^- fertilization at an appropriate ratio results in greater biomass accumulation compared with plants fed with either nitrogen source alone.[7] In tomatoes, some of the damaging effects of salinity have been averted by partial substitution of nitrate with ammonium in the nutrient solution.[8] In melons and tomatoes, improved plant growth and higher yield were obtained with addition of low levels of NH_4^+ to the mainly nitrate containing fertigation solution.[4,9]

Tomato fruit flavor is affected to a great extent by three major factors: sugars, mainly fructose and glucose; acids, mainly citric and malic; and by numerous volatiles. High levels of sugars and acids, the ratio between these taste components, and the occurrence of the desired profile of volatiles being determined, greatly contribute to the total flavor of the tomato.[10]

Saline conditions markedly improve tomato and other fruit quality components due to reduction in water accumulation in the pericarp, and the consequent increase in sugar and acid concentrations. However, fruit yield is usually lower under salinity than in control.[11] There is evidence that under saline condition, some fertilization regimes result in higher yields than others do.[12]

Only little is known about the beneficial effects of NH_4^+/NO_3^- combinations in the nutrient solution on tomato yield and quality under saline conditions. The objective of this study was to determine the combined and/or sole effects of NO_3^- and NH_4^+ under saline conditions on quality and yield of tomato genotypes with different fruit sizes, yields and fruit flavors, under protected growing conditions.

MATERIALS AND METHODS

Plant Material and Culture Conditions

Four indeterminate tomato hybrids (“R144”, “FA612”, “FA624”-Hazera Genetics, Brurim, Israel and “R175”-Zeraim Gedera, Gedera, Israel) were used in three experiments. Commercially raised 30-day-old seedlings were transplanted into 10 L pots containing 4-mesh washed perlite, one plant per pot. Fertigation regimes with designated nutrient solutions (NS) are detailed below. Standard cultural practices were applied throughout. Greenhouse experiments (Experiments 1 and 2) were conducted through the spring period and net house experiment

(Experiment 3) at the summer period. Plant spacing was 0.4 or 0.6 m^2 in the greenhouse and net house, respectively. Maximum greenhouse temperature exceeded 32°C (using wet mattress) and maximum 34°C at the net house. Shading level at both greenhouse and net house was 15%. Plants were topped below the seventh truss, after the setting of the sixth truss was confirmed. All the experiments were conducted in the experimental farm of the faculty of agriculture, Rehovot, Israel.

Experiment 1. Effects of Salinity and N-Source on Tomato Fruit Yield and Quality (cv. "R144")

Seedlings were transplanted into 10 L plastic pots. Micro-irrigation (Ein-Tal, Caesarea, Israel) driven by gravitation (from 500 L containers) allowed a continuous and constant flow (400–500 mL h^{-1}), thus maintaining constant moisture content in the growing medium and preventing salt accumulation due to evapo-transpiration. Nitrification was inhibited by 3,4-dimethylpyrazole phosphate (DMPP), at 2 ppm, to ensure the predetermined level of ammonium in both the fertigation solution and the growing medium.[13] Plants were grown from mid February to mid-June in a heated greenhouse (minimum night temperature, 14°C).

The basic nutrient solution consisted of N : P : K at 8 : 1 : 6 mM (Table 1). Nitrogen was applied as NH_4^+ at 0, 1, 2, or 4 mM mixed with NO_3^- to a total N of 8 mM in the NS. Salinity treatment commenced 10 days after transplanting, and salt concentration was gradually increased from 0 to 45 mM NaCl over 14 days to generate two electrical conductivity (EC) levels: 2.7 (control) and 7.4 dS m^{-1}, respectively. The experimental design was two-factorial with five randomized blocks. Each plot contained two plants.

Experiment 2. Effect of Salinity on Yield and Quality of Four Tomato Hybrids

Two large- and two small-fruit tomato hybrids, "R-144" and "R-175", and "FA612" and "FA624", respectively, were grown as in, and concomitantly with Experiment 1. Details of NS composition are given in Table 1. The experiment design was hierarchical-factorial with five randomized blocks. Each plot contained six plants.

Table 1. Composition and concentration of nutrient solutions used for tomato fertigation in greenhouse (Exps. 1–2) and net-house (Exp. 3).

Treatment	KNO_3 (mM)	$Ca(NO_3)_2 \cdot 4H_2O$	$Mg(NO_3)_2 \cdot 6H_2O$ (mM)	$(NH_4)_2SO_4$ (mM)	$MgSO_4$ (mM)	K_2SO_4 (mM)	KH_2PO_4 (mM)	H_3PO_4 (mM)	NaCl (mM)
				Experiment 1					
1	3	1.5	1	0.0	0	1.5	0	1	0
2	2	1.5	1	0.5	0	2.0	0	1	0
3	1	1.5	1	1.0	0	2.0	1	0	0
4	1	1.5	0	2.0	1	2.0	1	0	0
5	3	1.5	1	0.0	0	1.5	0	1	45
6	2	1.5	1	0.5	0	2.0	0	1	45
7	1	1.5	1	1.0	0	2.0	1	0	45
8	1	1.5	0	2.0	1	2.0	1	0	45
				Experiment 2					
1	2	1.5	1	0.5	0	1.5	1	0	0
2	2	1.5	1	0.5	0	1.5	1	0	45
				Experiment 3					
1	3	1.5	1	0.0	0	1.5	0	1	0
2	3	1.5	0	1.0	1	1.5	0	1	0
3	3	1.5	1	0.0	0	1.5	0	1	20
4	3	1.5	0	1.0	1	1.5	0	1	20

Experiment 3. Effect of N-Source and Salinity on Yield and Water Uptake by Large and Small Tomato Hybrids "R-144" and "FA612"

Seedlings were transplanted at mid June into 20 L plastic pots. The surface was mulched with black plastic net, to reduce evaporation and algal growth. Two NH_4^+ concentrations (0 and 2 mM of total 8 mM N) were combined with 0 or 20 mM NaCl. N : P : K at 8 : 1 : 6 mM was maintained throughout (Table 1), and recycled fertigation was applied using an air lift system.[14] The NS was freshly prepared once every 7 to 10 days, and supplemented with a micronutrient mixture (with EDTA as a chelating agent) to yield: B (0.4), Mn (0.54), Cu (0.04), Zn (0.27), Fe (1.1) and Mo (0.03) ppm. One-minute fertigation pulses were given once every 45 min to prevent salt accumulation by perpetual rinsing of the growing medium. Each plant was placed above a 120 L drainage container and the volume and composition of the NS was monitored regularly. One or two main stems were allowed to grow until six trusses were set in cvs. "R144" and "FA612", respectively. The experimental design was two-factorial with five randomized blocks, two plants per pot.

Sampling and Observations

Transpiration rate and stomatal conductance (Porometer, LI-1600, LI-COR, Inc.) were measured at three intervals of 15 days during the period of fruit setting and development (30/08–30/09), Water uptake in the net-house experiment, was monitored by measuring the water level in the NS container. Leaf area was recorded at the end of the experiment (LI 3000 Area meter, LI-COR, Inc., Nebraska, USA). All plant leaves were removed, oven-dried (60°C), grinded to pass through 20 mesh screen, the grinded material was mixed thoroughly and 2 replicates, each of 100 mg were digested with H_2SO_4 and H_2O_2 and diluted to 100 mL. The solution was used for colorimetric determination of nitrogen,[15] phosphorus,[16] and by flame photometer for potassium.

Fruits were harvested regularly five days after breaker stage, and fresh weight was determined for each fruit separately. Fruit with blossom end rot (BER) and immature fruits (IF) were counted, weighed and discarded. Total soluble solids (TSS) of each fruit was measured with an ATAGO PR-100 refractometer; titratable acidity by potentiometric titration to pH value of 8.1 using 0.1 M NaOH,[17] pH and EC of ripe tomatoes were measured at harvest in the fruit serum by pH and conductivity meters (Radiometer, Copenhagen).

Data were statistically analyzed by JMP software, using general least-square models.

RESULTS

The effect of increasing ammonium concentration in the nutrient solution resulted in decreasing the marketable yield in both control and salt treatments (Table 2). In the presence of salt no significant effect of ammonium on marketable tomato yield was observed up to 2 mM NH_4^+, but 4 mM NH_4^+ reduced it to about 25% of the yield at zero ammonium without salt. Increase in NH_4^+ in the solution tends to increase BER. The highest ammonium concentration resulted in the lowest LAI at both NaCl levels as compared with 1 or 2 mM NH_4^+ (Table 2).

With 8 mM nitrate as sole N-source (Table 3), N concentration in the leaves was significantly lower under salinity as compared to the non-salt treatment. In the non-salt and the salt treatments, N concentration in the

Table 2. The effect of N-source and salinity on fruit yields and fruit quality in cv. "R144" (Exp. 1).

*NH_4^+ (mM)	MY[a] (g plant^{-1})	BER[b] (g plant^{-1})	TY[c] (g plant^{-1})	MFW[d] (g)	TSS[e] (%)	FSEC[f] (dS m^{-1})	TA[g] (%)	pH	LAI[h] (m^2 plant^{-1})
				NaCl—0 mM					
0	5480ab	158d	6084b	141a	5.3b	5.3c	0.51b	4.07a	1.8ab
1	5980a	236c	6814a	143a	5.4b	5.3c	0.48b	4.04a	2.0a
2	5160bc	247c	4906cd	140a	5.5b	5.5c	0.53b	4.00a	1.8ab
4	4430c	356c	5927b	126b	5.2b	5.1c	0.46b	4.04a	1.6b
				NaCl—45 mM					
0	2810d	763b	3663e	82d	7.3a	6.9ab	0.67a	4.02a	1.2c
1	3320d	821b	4340de	103c	6.6a	7.2a	0.64a	4.00a	1.6b
2	2700d	954ab	3914e	89cd	7.2a	7.2a	0.64a	3.96a	1.5b
4	1670e	1183a	2919f	87d	6.9a	6.4b	0.43b	3.98a	1.1c

*Concentration of ammonium out of total 8 mM N as $NH_4^+ + NO_3^-$.
[a]MY, marketable yield; [b]BER, blossom end rot; [c]TY, total yield = MY + BER + developing fruits; [d]MFW, mean fruit weight; [e]TSS, total soluble solids; [f]FSEC, fruit serum electrical conductivity; [g]TA, titratable acidity as citric acid; [h]LAI, leaf area index.
Within each column, means followed by the same letter do not significantly differ at $P < 0.05$.

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Table 3. Effect of N-source and salinity on dry matter and N, K, and P concentration in tomato leaves of cv. "R144" (Exp. 1).

NO_3^- (mM)	NH_4^+ (mM)	LDM[a] ($g\,plant^{-1}$)	N	K	P
			($g\ kg^{-1}DM$)		
		NaCl—0 mM			
8	0	210bc	38b	35a	4.6a
7	1	265a	44a	36a	3.6b
6	2	227b	45a	36a	3.8b
4	4	198c	45a	36a	4.2ab
		NaCl—45 mM			
8	0	162cd	24d	28b	4.0ab
7	1	220bc	39b	28b	3.0c
6	2	209bc	43ab	33a	3.6b
4	4	148d	32c	32ab	4.1ab

[a]LDM, leaf dry matter. Within each column, means followed by the same letter do not significantly differ at $P < 0.05$.

leaves increased with the presence of 1 or 2 mM NH_4^+ as compared to sole nitrate treatment. When 1 or 2 mM NH_4^+ was maintained in the solution, the N concentration in the leaves was similar in the non-salt and the salt treatments. However, 4 mM NH_4^+ decreased N concentration in the salt treatment.

Irrespective of salinity, P concentration in the leaves was highest both when nitrate was the sole N-source and when NH_4^+ at 4 mM was present in the NS. Nevertheless, total uptake was highest at 1 or 2 mM NH_4^+ in the NS. K concentration was lowest under salt stress and was not affected by the N-source (Table 3).

High salt treatments (45 mM NaCl) resulted in low yields of marketable fruit (Tables 2 and 4) and in total plant dry matter (DM) as compared with controls (Tables 3 and 4). The addition of 1 mM ammonium had a beneficial effect regardless of the EC level. In Experiment 1, plots fertigated with ammonium had higher fruit yield and leaves DM (Tables 2 and 3), but yield was lowest in plots treated with 4 mM NH_4^+ and high salt.

Fruit sizes of "FA612" and "R144" were the least and most affected by salt stress, respectively (Table 4). In "R144", the adverse salinity effects were low in the presence of 1 mM NH_4^+ (Exp. 1, Table 2). However, the incidence of BER increased in the presence NH_4^+, and was highest in plots fertigated with high ammonium and salt (Exp. 1, Table 2).

Table 4. The effect of salinity on fruit yield and phisiological charactheristic of four tomato hybrids (Exp. 2).

Cultivar	MY[a] Fruit yield ($g\,plant^{-1}$)	BER[b]	MY[a] Fruit number ($plant^{-1}$)	BER[b]	MFW[c] (g $plant^{-1}$)	LDM[d]	LDM/MY[e]	LAI[f] m^2 ($plant^{-1}$)	FDP[g] g day^{-1} ($plant^{-1}$)
					NaCl—0 mM				
R144	3860a	0	44b	0	109a	177a	43.9	1.8a	1.96a
R175	3337a	0	51a	0	84b	175a	50.4	1.7ab	1.75ab
FA612	2256bc	0	55a	0	44e	155ab	69.5	1.6ab	1.23c
FA624	2764b	0	46b	0	70c	170a	60.1	1.5b	1.02c
					NaCl—45 mM				
R144	2102c	454a	36d	4	78b	158ab	59.2	1.4a	1.68b
R175	2212c	407a	44bc	5	65c	126c	46.9	1.3a	1.56b
FA612	1950c	36b	52a	1	38e	115c	57.4	1.3a	1.15c
FA624	1940c	25b	44bc	1	52d	131bc	65.6	1.2a	0.97c

[a]MY, marketable yield; [b]BER, blossom end rot; [c]MFW, mean fruit weight; [d]LDM, leaves dry matter; [e]LDM/MY ratio; [f]LAI, leaf area index; [g]FDP, fruit development period/fresh weight.
Within each column, means followed by the same letter do not significantly differ at $P < 0.05$.

The two small-fruit genotypes were less susceptible to BER under salinity than the large-fruit hybrids (Exp. 2, Table 4).

In Experiment 3, the decrease in LAI in response to salt did not cause a decrease in yield in cv. "FA612" whereas in cv. "R144" a decrease in LAI was accompanied by a yield reduction (Table 5). Specific leaf weight (SLW) was significantly higher with the addition of 2 mM NH_4^+ compared to only nitrate treatment in the control and salt treatments. Plant DM was higher in "R144" and lowest in "FA612" fertigated with 2 mM NH_4^+ compared to nitrate as the sole N-source (Table 5).

Transpiration rates were higher in "FA612" than in "R144" (Exp. 3, Table 5), and NH_4^+ at 2 mM (Exp. 3, Table 5) resulted in a slight increase in water uptake (CWU) by the plant under salinity and control in both hybrids.

NH_4^+ in the NS had no effect on fruit TSS, at either high or low salinity, but EC in the fruit serum was higher in plants treated with 1 or 2 mM NH_4^+ combined with a high salt NS (Table 2). With the exception of fruit pH, high salt level contributed markedly to the improvement of fruit quality (TSS, EC, and titratable acidity) in all the hybrids except

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Table 5. The effect of N-form and salinity on fruit yield and fruit pH of two tomato hybrids in Exp. 3.

Cultivar	*NH_4^+	Yield g (plant^{-1})	MFW[a] g (plant^{-1})	CWU[b] L (plant^{-1})	E[c] m mol H_2O (m^{-2} s^{-1})	DM[d] g (plant^{-1})	SLW[e] cm^2 (g^{-1})	LAI[f] m^2 (plant^{-1})	TSS[g] (%)	TA[h] (%)
					NaCl—0 mM					
R144	0	3702a	123b	180b	9.8b	320b	45b	2.5a	5.1b	0.48c
	2	4087a	136a	202ab	9.3b	370a	65a	2.3a	5.5b	0.44c
FA612	0	3611a	50c	199ab	11.4a	302b	50b	2.2ab	6.6a	0.55b
	2	3700a	51c	210a	10.9ab	286b	72a	1.8cd	6.5a	0.53b
					NaCl—20 mM					
R144	0	3005b	100b	170b	10.4b	300b	42b	2.1ab	7.3a	0.62a
	2	3423ab	114a	184b	9.8b	320b	54b	2.0bc	7.2a	0.57ab
FA612	0	3417ab	47c	185b	11.9a	352a	52b	1.9c	7.0a	0.57ab
	2	3801a	53c	208a	10.4b	294b	74a	1.6d	7.2a	0.57ab

*Concentration of ammonium out of total 8 mM N as $NH_4^+ + NO_3^-$.
[a]MFW, mean fruit weight; [b]CWU, cumulative water uptake; [c]E, transpiration rate; [d]DM, dry matter; [e]SLW, specific leaf weight; [f]LAI, leaf area index; [g]TSS, total soluble solids; [h]TA, titratable acidity as citric acid.
Within each column, means followed by the same letter do not significantly differ at $P < 0.05$.

cv. ‘‘FA612’’ (Tables 2 and 4). In the net-house experiment, TSS in fruits of cv. ‘‘FA 612’’ was unaffected by salinity, while a significant increase in TSS was recorded in ‘‘R144’’ with salinity (Table 5).

DISCUSSION

Ammonium Effect on Yield

Plants take up nitrogen mainly as nitrate and ammonium. When both are present in solution ammonium uptake is preferred.[18] Under salt stress, nitrate uptake is slowed down[19] and salinity reduces NO_3^- assimilation[20] with the possible consequence of N deficiency in the plant. Reinforcement of the NS with 1 or 2 mM NH_4^+ has an ameliorating effect on salt-stressed plants[21] probably due to the additional uptake of nitrogen as NH_4^+ from the NS.[8,22] Consequently a higher N concentration was found in salt stressed leaves (Table 3), but higher ammonium levels caused yield reduction[9] (Table 2).

High NH_4^+ levels may lead to reduced sugar concentration in the roots,[5] due to consumption of sugar by the ammonium metabolism in the root. Ammonium may cause disruption of many metabolic processes.[18] Reduced uptake of calcium due to the competition with ammonium[23] may cause its deficiency in the fruit, with the consequent increased susceptibility to BER and/or hampered fruit expansion.[24] In our experiments we applied surplus amounts of calcium (4 mM) to avoid deficiency,[24] and NS analysis showed no disturbance in calcium uptake (data not shown).

BER Incidence

The number of BER affected fruits increased with the addition of NH_4^+, and salt application further worsened the situation[25] (Table 2). The relatively small reduction in yield of the small-fruit hybrids ‘‘FA612’’ and ‘‘FA624’’ under high salinity is partially attributed to the lower incidence of BER as compared to ‘‘R-144’’ and ‘‘R-175’’ (Table 4). The small-fruited cultivars tested here have a slower fruit-growth rate than the large-fruited hybrid [1–1.2 and 1.8–2 g day^{-1}, respectively (Table 4)]. In tomatoes, the severity of BER depends, in part, on fruit growth rate,[26] and small-fruited cultivars are known to be less susceptible to salinity.[27]

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Genotype Response to Salt

In tomatoes, an EC increase of $1\,dS\,m^{-1}$ above the threshold of $2.5\,dS\,m^{-1}$, results in a yield decrease of ca. 10%.[28] Yield and fruit weight of the smaller-fruit hybrid (''FA612'') were less affected by salinity than those of larger fruit (''R144'')[29] (Table 5). Under low saline conditions, small fruit hybrids had similar dry weight per plant but higher shoot/fruit ratio as compared with the large fruit hybrids (Table 4). In the latter, shoot/fruit ratio was probably close to optimum and thus the decrease in LAI and leaf DM in response to salinity resulted in yield reduction. In contrast, in the small fruit hybrids the decrease in leaves DM and LAI (Table 4) is probably not detrimental and is, therefore, sufficient for supporting fruit growth. This was evident in the third experiment where even mild salinity (20 mM NaCl), with the consequent slight reduction in LAI resulted in yield reduction in cv. ''R144'' but not in cv. ''FA612'' (Table 5).

Fruit Size and Quality

Within each cultivar, fruit numbers were not affected by the fertigation treatment. Hence, yield reduction is mostly attributed to the decline in fruit weight[30] (Table 3). Water uptake by tomato plants declines with the increase in salt concentrations in the irrigation water[31] causing the decrease in fruit weight.[27] Ammonium supplement at 1 or 2 mM of total 8 mM N (Tables 2 and 5) resulted in heavier fruit, but not at 4 mM NH_4^+, at both EC levels[32] (Table 2).

Differences in fruit size may result from the following: (1) reduced water transport towards the fruit,[33] (2) retarded fruit growth rate,[24] and (3) the numbers of cells determined in the first phase of fruit growth or the extent of cell expansion through the second phase of fruit growth.[27] These observations show that ammonium slightly decreased transpiration and LAI while total water uptake increased (Table 5). If only water transport to the fruit had been higher, TSS would have been expected to decrease due to a ''dilution effect''. However, TSS remained similar, regardless of the N-form (Table 5), it is therefore unlikely that ammonium application increased water transport to the fruit. Harvesting time was delayed by one week with ammonium supplementation (data not shown). The extended fruit development period is most probably the reason for the increased fruit size. Similarly, the presence of ammonium in the NS also prolonged the fruit development period in melons and resulted in heavier fruits.[22]

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Table 6. Effect of salinity on fruit quality components of four tomato hybrids in Exp. 2.

	NaCl—0 mM				NaCl—45 mM			
Cultivar	TSS[a] (%)	BY[b] (g plant^{-1})	FSEC[c] (dS m^{-1})	TA[d] (%)	TSS[a] (%)	BY[b] (g plant^{-1})	FSEC[c] (dS m^{-1})	TA[d] (%)
R144	5.1c	198a	5.9c	0.51d	6.3b	138b	6.9ab	0.65b
R175	5.5c	176a	5.6c	0.53d	6.1b	144b	6.7b	0.57cd
FA612	6.5ab	153b	6.7b	0.79a	6.9a	133b	7.4a	0.74a
FA624	6.1b	172a	6.0c	0.56c	7.1a	150b	7.3a	0.61bc

[a]TSS, total soluble solids; [b]BY, brix yield; [c]FCEC, fruit serum electrical conductivity; [d]TA, titratable acidity as citric acid.
Means followed by the same letter within each column are not significantly different at $P < 0.05$. The results are means for the whole growing period.

Increased salinity in the NS contributed to improved fruit quality in terms of TSS, acidity, and pH. These results with large fruit hybrids (Tables 2, 5, and 6) are in good agreement with this common knowledge.[34,35] However, TSS remained almost unchanged in cv. "FA612", even under saline conditions (Tables 4 and 6). When one compares TSS values on similar fruit weight range (2–3 kg plant^{-1}) the small-fruit hybrids has higher TSS values than the large-fruit hybrids and the extrapolation shows that TSS in cv. "FA612" remains higher through all the regression line (Fig. 1). The point is further strengthened when yields of Experiment 2 are compared to Experiment 3. In the latter experiment, plants of cv. "FA612" had two leading stems, and thus total yields were almost similar to those of cv. "R144" (Table 5). This may point to a specific hybrid's ability to maintain its TSS even under relatively high yield. It is possible that the selection for large fruit on one hand and for flavor-rich hybrids may have resulted in a differential assimilates' distribution throughout the plant as reflected in higher shoot/fruit yield ratio in the small-fruit hybrid (Table 4).

In the large-fruit cv. "R-144", TSS was found to be closely linked to yield. In "FA-612", R^2 values for the regression lines between TSS and yield were much lower (Fig. 1), thus indicating that factors other than fruit yields may be involved in determining fruit TSS. Indirectly, the most likely factor to affect fruit TSS is the fruit size. Fruit size was relatively stable under salt stress in cv. "FA612" (Table 4). The capacity of storing sugars in the fruit is limited by its osmotic potential and varies among hybrids. It is possible that salinity slightly contributed to fruit TSS of

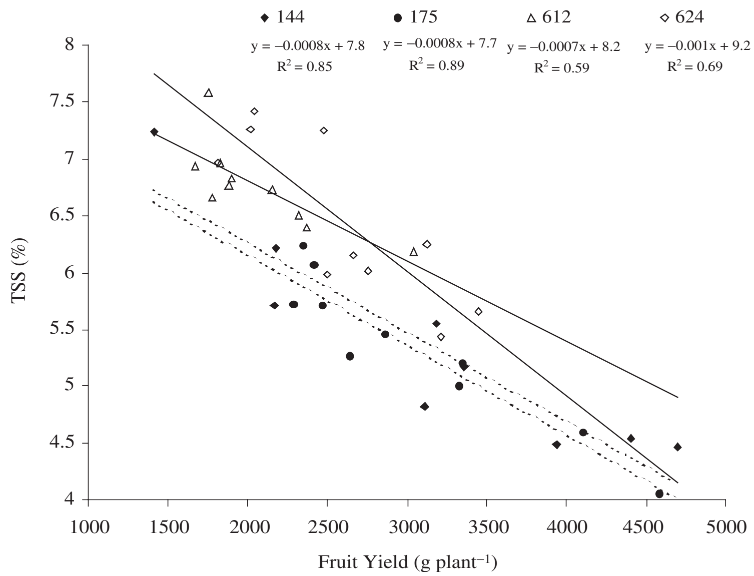

Figure 1. The correlation between TSS and fruit yield in four tomato hybrids.

cv. "FA612" due to its limited capacity to store sugars, while fruit TSS of cv. "R144" is largely varying by salt stress.[35]

A negative linear correlation between TSS and yield was found in all tested hybrids. However, the ratio of TSS decline versus yield differed among the hybrids. It was the least and most in cvs. "FA612" and "FA624", respectively (Fig. 1). A similar trend in cv. "R144" was observed,[35] by applying various saline solutions to plants at different physiological ages. Since fruit yields are usually lower in small-fruit hybrids, the extent to which salt stress affect TSS content would be expected to be lower in those hybrids. This was evident only in cv. "FA612".

Different strategies to improve fruit quality with minimal yield loss were suggested.[35–37] Evaluation of TSS vs. yield response for a specific hybrid offers the possibility of controlling fruit quality by salt level with minimum reduction in total fruit yield.

CONCLUSIONS

These results suggest three possible ways of counteracting the adverse effects of salinity in hydroponically grown tomato: (1) the use of mainly

NO_3^- with the addition of up to 1 mM NH_4^+ to improve fruit size with minimal loss of fruit quality; (2) the use of small fruit cultivars which are less susceptible to salinity up to 45 mM NaCl; and (3) the use of mild saline conditions (20 mM NaCl) in the nutrient solution which hardly reduces yield but significantly improves fruit quality.

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